The fast multi-level fuzzy edge detection of blurry images

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Abstract

To realize the fast and accurate detection of the edges from the blurry images, the fast multi-level fuzzy edge detection (FMFED) algorithm is proposed. The FMFED algorithm first enhances the image contrast by means of the fast multi-level fuzzy enhancement (FMFE) algorithm using the simple transformation function based on two image thresholds. Second, the edges are extracted from the enhanced image by the two-stage edge detection operator which identifies the edge candidates based on the local characteristics of the image and then determines the true edge pixels using the edge detection operator based on the extreme of the gradient values. Experimental results demonstrate that the FMFED algorithm can extract the thin edges and remove the false edges from the image, which leads to its better performance than the Sobel operator, Canny operator, traditional fuzzy edge detection algorithm and other multi-level fuzzy edge detection algorithms.

Keywords: blurry images, edge detection, fuzzy enhancement, image thresholds

1 Introduction

Machine vision is widely used in modern mechanical systems, such as semiconductor end-package equipments, surface mounting machines and mobile robots et al. But the images acquired by the CCD camera in these equipments are generally influenced by such factors as vibration of the mechanical structure, quality and resolution of cameras and illumination variations et al. These disadvantageous factors usually will lead to the fuzziness of the images and make it difficult to realize the accurate edge detection of the blurry images.

To extract the edges from the images, derivative edge detection operators, such as Sobel operator, Roberts operator and Laplacian operator et al., are commonly used. These operators are computationally simple while they cannot extract edge information from the blurry images satisfactorily [1]. The traditional fuzzy edge detection (TFED) algorithm introduces the fuzzy enhancement method and is suitable for edge detection of some blurry images [2-3]. The algorithm first enhances the image by means of mapping transformation, fuzzy enhancement operator and inverse mapping transformation and then extracts the edge information from the enhanced image using 'min' or 'max' operator. This algorithm is computationally complex because the mapping transformation involves the exponential calculation and it will lead to the loss of pixels with low gray value. In addition, the "min" or "max" operator has a relatively lower edge positioning accuracy in extracting edges from the images.

Many authors have presented various improved algorithms with the simplified mapping transformation and optimized fuzzy enhancement operator [4-7]. Although these algorithms can overcome the deficiency of TFED to some degree, they are not fit for complex blurry images because they will enhance some edge pixels in the image at expense of the weakening of other edges. To circumvent this problem, a fast multi-level fuzzy edge detection (FMFED) algorithm is proposed. The FMFED algorithm involves image enhancement using the fast multi-level fuzzy enhancement (FMFE) method and edge detection of the enhanced image using two-stage detection operator. The FMFE method realizes the multi-level fuzzy enhancement of the image using a simple transformation function based on the image thresholds and a fuzzy enhancement operator. The two-stage detection operator first identifies the edge candidates based on the local characteristics of the image and then determines the true edge pixels using the edge detection operator based on the extreme of the gradient values.

2 FMFED algorithms

2.1 FMFE ALGORITHM

The FMFE algorithm first acquires the optimal threshold Q based on the distribution of the gray values in the image. Suppose the gray values in the image are $g_0, g_1, \cdots, g_n$ ($g_0 < g_1 \cdots < g_n$) and for any one gray value g_i $(i = 0, \cdots, n)$ the number of pixels with their gray values equal to g_i is q_i, then the mathematical expectation value of all the gray values can be computed. Because the pixels with gray values equal to 0 have a degrading influence on the computation of the optimal threshold, these pixels should be excluded to produce the appropriate threshold Q.

$$Q = \begin{cases} \dfrac{\sum_{i=1}^{n} g_i q_i}{\sum_{i=1}^{n} q_i} & g_0 = 0 \\ \dfrac{\sum_{i=0}^{n} g_i q_i}{\sum_{i=0}^{n} q_i} & g_0 \neq 0 \end{cases} . \quad (1)$$

Obviously, the threshold Q means the weighted average of non-zero pixel values. Based on the optimal threshold Q, all the pixels in the image can be classified into the two sets, namely, F_O with high gray values and F_B with low gray values. The mean value A_O for the set F_O and A_B for the set F_B can be computed.

$$A_O = \frac{\sum_{f_{i,j}\in F_O} f_{i,j}}{S_O}, \tag{2}$$

$$A_B = \frac{\sum_{f_{i,j}\in F_B} f_{i,j}}{S_B}, \tag{3}$$

where S_O and S_B denote the sum of objects pixels and the sum of background ones, respectively.

For any one pixel (i, j), the linear mapping transformation G is determined to convert the gray value $f_{i,j}$ into the characteristic value $p_{i,j}$ in the fuzzy domain.

$$p_{i,j} = G\left(f_{i,j}\right) = \begin{cases} \dfrac{f_{i,j}-f_{\min}}{A_B-f_{\min}} & f_{i,j}\le A_B \\ \dfrac{A_O+A_B-2f_{i,j}}{A_O-A_B} & A_B < f_{i,j} \le \dfrac{A_O+A_B}{2} \\ \dfrac{2f_{i,j}-A_O-A_B}{A_O-A_B} & \dfrac{A_O+A_B}{2} < f_{i,j}\le A_O \\ \dfrac{f_{\max}-f_{i,j}}{f_{\max}-A_O} & f_{i,j} > A_O \end{cases}, \tag{4}$$
$$i = 1,2\cdots,M;\ j=1,2\cdots,N$$

where $f_{\max}$ and $f_{\min}$ denote the maximal gray value and the minimal one in the image. M and N denote the rows and columns of the image, respectively.

When the image is changed from the spatial domain into the fuzzy domain, the fuzzy enhancement operator H_r is adopted to realize the function of image enhancement.

$$p'_{i,j} = H_r(p_{i,j}) = H_1(H_{r-1}(p_{i,j})), \tag{5}$$

$$H_1(p_{i,j}) = \begin{cases} \dfrac{p_{i,j}^2}{t} & 0\le p_{i,j}\le t \\ 1-\dfrac{(1-p_{i,j})^2}{1-t} & t < p_{i,j}\le 1 \end{cases} \tag{6}$$

where r denotes the iterative times and it has a great influence on the image enhancement effect. To enhance the image moderately, r is usually chosen as 2 or 3. t denotes the fuzzy characteristic threshold and it can be chosen more flexibly in the FMFE algorithm than the traditional fuzzy enhancement algorithm with t predefined as 0.5 .

Following the enhancement operation in the fuzzy domain, the inverse mapping transformation G^{-1} is taken to change the image from the fuzzy domain into the spatial domain.

$$h_{i,j} = G^{-1}(p'_{i,j}) = \begin{cases} (A_B-f_{\min})p'_{i,j}+f_{\min} & f_{i,j}\le A_B \\ \dfrac{A_O+A_B-(A_O-A_B)p'_{i,j}}{2} & A_B < f_{i,j}\le \dfrac{A_O+A_B}{2} \\ \dfrac{(A_O-A_B)p'_{i,j}+A_O+A_B}{2} & \dfrac{A_O+A_B}{2} < f_{i,j}\le A_O \\ f_{\max}-(f_{\max}-A_O)p'_{i,j} & f_{i,j} > A_O \end{cases}. \tag{7}$$
$$i=1,2\cdots,M;\ j=1,2\cdots,N$$

The curve of the FMFE algorithm is shown in Figure 1. It can be seen from Figure 1 that the FMFE algorithm can realize the multi-level enhancement of image because it involves three transition points.

2.2 TWO-STAGE EDGE DETECTION OPERATOR

(1) First-stage edge detection

The first-stage edge detection aims to determine the edge candidates. The gray values of the pixels on both sides of the edges in the image usually differ to some extent. To prevent the thick edges from being extracted, the edges are considered to be located on the side with the relatively low gray value. Based on this precondition, the first-stage edge detection operator is adopted.

For any one pixel (i, j) with its gray value equal to $h_{i,j}$, the 3×3 window cantered around (i, j) is chosen. The mean value $Z_{i,j}$ of the gray values of all the pixels in the window is computed. According to the relationship between $Z_{i,j}$ and $h_{i,j}$, the edge sign $b_{i,j}$ will be determined.

$$b_{ij} = \begin{cases} 1 & h_{i,j} < Z_{i,j} \\ 0 & h_{i,j} \ge Z_{i,j} \end{cases}, \tag{8}$$

where $b_{i,j}$ =0 means that the pixel (i, j) is not the edge pixel while $b_{i,j}$ =1 means the pixel will be the edge candidate and the second-stage edge detection must be implemented to verify if it is the true edge pixel.

(2) Second-stage edge detection operator

For the pixel (i, j) with $b_{i,j}$ =1, the 5×5 detection window cantered around (i, j) is chosen and it is divided into eight sub-windows shown in Figure 2. Let the four pixels included in the l^{th} ($l=0\cdots7$) sub-window as (r_0^l,c_0^l), (i,j), (r_1^l,c_1^l) and (r_2^l,c_2^l). The gradient values for the pixel (i, j) and two neighbouring pixels in this sub-window can be defined as:

$$\begin{aligned} d_{r_0^l,c_0^l} &= \left|g_{i,j}-g_{r_0^l,c_0^l}\right| \\ d_{i,j}^l &= g_{r_1^l,c_1^l}-g_{i,j} \\ d_{r_1^l,c_1^l} &= \left|g_{r_2^l,c_2^l}-g_{r_1^l,c_1^l}\right| \end{aligned}. \tag{9}$$

According to the relationship between $d_{r_0^l,c_0^l}$, $d_{i,j}^l$ and $d_{r_1^l,c_1^l}$, the additional edge sign $b_{i,j}^l$ for the pixel (i, j) in every sub-window is determined.

$$b_{i,j}^l = \begin{cases} 1 & b_{i,j}=1 \quad and \quad d_{i,j}^l > d_{r_0^l,c_0^l} \quad and \quad d_{i,j}^l > d_{r_1^l,c_1^l} \\ 0 & otherwise \end{cases}. \tag{10}$$

All the gradient values for the pixel (i, j) with $b_{i,j}^l$ =1 in the sub-windows constitute $D_{i,j}$.

$$D_{i,j} = \left\{d_{i,j}^l \,\middle|\, b_{i,j}^l = 1, l = 0\cdots7\right\}. \tag{11}$$

The maximal gradient value in $D_{i,j}$ will be used as the ultimate gradient value for the pixel (i, j) in the 5×5 detection window and the edge image will be produced when the gradient values of all the pixels in the enhanced image have been gotten.

$$d_{i,j} = \begin{cases} Max\{D_{i,j}\} & D_{i,j} \neq \Phi \\ 0 & D_{i,j} = \Phi \end{cases}, \tag{12}$$

where Φ denotes null set.

3 The experiments and analysis

In order to prove the validity of the FMFED algorithm, the Sobel operator, Canny operator [8], TFED algorithm, the improved multi-level fuzzy edge detection (IMFED) algorithm presented in reference [7] and the proposed algorithm in this paper are used to extract edge information from the 351×325×8bits chip image shown in Figure 3 (a) and the 230×224×8bits standard module image which is used for the calibration in the visual system shown in Figure 4(a). The edge image is segmented to the binary image using the iterative algorithm provided in references [9-10]. The edge detection performance of these methods is compared in terms of the image quality and computation efficiency.

The visual comparisons of edge images resulting from the five edge detection algorithms used for the chip image and module image are shown in Figure 3 and Figure 4, respectively. It can be seen from the results from the five edge detection algorithms that Sobel operator performs worst among all the five algorithms in that it extracts too many false edges and the extracted edges are thick and discontinuous. The Canny operator can extract fine edges while it also acquires some false edges. Apart from extracting the thick edges, the TFED and IMFED algorithms lead to the loss of the important edge. For example, the two algorithms fail to detect the right edge of some chips in the image shown in Figure 3(a). The FMFED algorithm presented in this paper performs significantly better than the above discussed algorithms in that it not only obtains the fine and continuous edges but also removes the false edges in the image.

All the five algorithms programmed in VC++ language are run on the Intel Pentium III computer (CPU: 477MHz; RAM: 120M). For each algorithm, it is implemented for ten times and the average time spent for the ten implementations is used as the run time. The approximate run time of these algorithms used for the chip image and module image is shown in TABLE I. Here it should be noted that the run time excludes the time involved in the digitalization of the edge image. The non-optimized FMFED algorithm means it is implemented based on the single pixel in the image while the optimized algorithm means it is carried out based on the one-dimensional histogram of the image. It can be seen from TABLE I that the non-optimized FMFED algorithm runs slightly slower than the Sobel operator while it is implemented more quickly than the TFED algorithm and Canny operator. The optimized FMFED algorithm has the highest computation efficiency than other algorithms. The comparison between the run time for the chip image and that for the model image can demonstrate that the advantage of FMFED algorithm over other algorithms in the computation efficiency is more obvious with the increasing image size.

Owing to the adjustability of the fuzzy characteristics threshold t in the FMFED algorithm, its influence on the run time is studied roughly. The relationship between t ranging from 0 to 1 and run time for the non-optimized FMFED algorithm operating on the chip image and module image is shown in Figure 5. It can be seen that the run time of the FMFED algorithm is robust to the change of fuzzy characteristic threshold. This means that the fuzzy characteristic threshold has the minor influence on the run time although it will influence the image quality greatly.

4 Conclusions

The fast multi-level fuzzy edge detection (FMFED) algorithm presented in this paper defines new mapping transformation according to the predefined threshold, which avoids the complex calculation of TFED algorithm and loss of edge information with low gray level. Through the proper selection of fuzzy characteristic threshold, the adaptability of the algorithm is enhanced and the multi-level image enhancement is realized. The presented two-stage edge detection operator can extract fine and continuous edge information from enhanced images, which overcomes such defect of the TFED and IMFED algorithms as the thick edges will be extracted. Indeed, the FMFED algorithm can effectively fulfil the edge detection of the blurry images and it performs better than the Sobel operator, Canny operator, the TFED algorithm and some other improved algorithms.

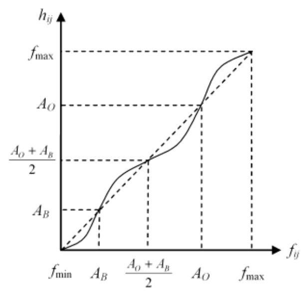


FIGURE.1 Curve of fast multi-level fuzzy enhancement

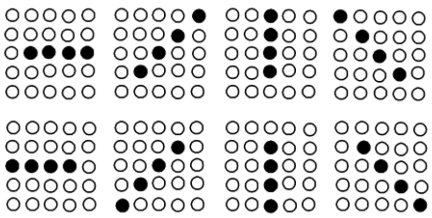
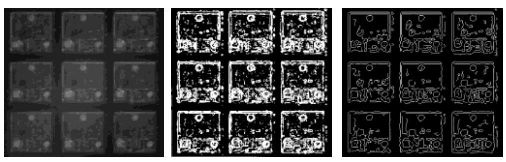
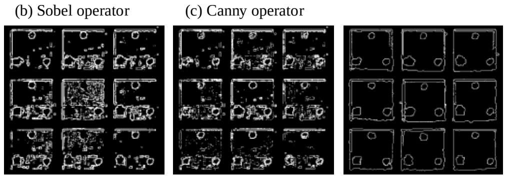


FIGURE.2 Partition of the detection window



(b) Sobel operator (c) Canny operator



(e) IMFED algorithm (f) FMFED algorithm

FIGURE. 3 Chip image and results of five edge detection algorithms

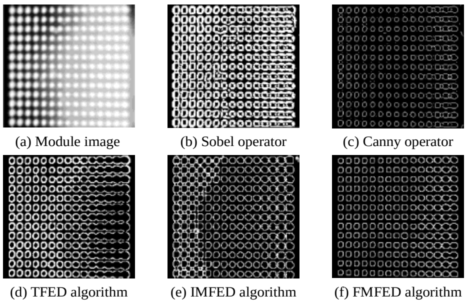


Fig.4 Module image and results of five edge detection algorithms

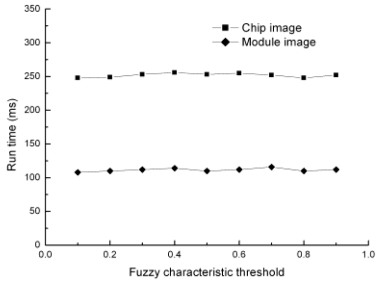


FIGURE. 5 The relationship between the two algorithm

TABLE 1 The run time for five edge detection algorithms

Edge detection algorithm	Run time(ms)	
	Chip image	Module image
Sobel	238	106
Canny	898	282
TFED	378	180
IMFED	264	116
FMFED (not optimized)	253	114
FMFED (optimized)	131	59

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